OPEN-FILE REPORT 98-18

SEISMIC HAZARD EVALUATION OF THE INGLEWOOD 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

1998

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

STATE OF CALIFORNIA
GRAY DAVIS
GOVERNOR

THE RESOURCES AGENCY
MARY D. NICHOLS
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DARRYL YOUNG
DIRECTOR

JAMES F. DAVIS, *STATE GEOLOGIST*

OPEN-FILE REPORT 98-18

SEISMIC HAZARD EVALUATION OF THE INGLEWOOD 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

DIVISION OF MINES AND GEOLOGY'S PUBLICATION SALES OFFICES:

Southern California Regional Office
655 S. Hope Street, Suite 700
Los Angeles, CA 90017
(213) 239-0878

Publications and Information Office
801 K Street, MS 14-31
Sacramento, CA 95814-3531
(916) 445-5716

Bay Area Regional Office
185 Berry Street, Suite 210
San Francisco, CA 94107-1728
(415) 904-7707

CONTENTS

ILLUSTRATIONS

PREFACE

With the increasing public concern about the potential for destructive earthquakes in northern and southern California, the State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans.

3. **The State Mining and Geology Board (SMGB)** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The SMGB also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology (DMG) to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and adopted by the California SMGB.

The Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These Open-File Reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Open-File Reports are not available through BPS Reprographic Services.**

DIVISION OF MINES AND GEOLOGY OFFICES

Geologic Information and Publications Office
801 K Street, MS 14-33
Sacramento, CA 95814-3532
(916) 445-5716

Bay Area Regional Office
185 Berry Street, Suite 210
San Francisco, CA 94107-1728
(415) 904-7707

Southern California Regional Office
655 S. Hope Street, Suite 700
Los Angeles, CA 90017
(213) 239-0878

WORLD WIDE WEB ADDRESS

Seismic Hazard Evaluation Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage:
http://www.consrv.ca.gov/dmg/shezp/

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that the 1) process for zoning liquefaction hazards remain unchanged and that 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high-water-table information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Inglewood 7.5-Minute Quadrangle (scale 1:24,000).

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Inglewood 7.5-Minute Quadrangle, Los Angeles County, California

By

Cynthia L. Pridmore

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Inglewood 7.5-minute Quadrangle (scale 1:24,000). This section and Section 2 addressing earthquake-induced landslides are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/.

BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated granular sediments at depths less than 40 feet subsurface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Inglewood Quadrangle.

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although the selection of data used in this evaluation was rigorous, the State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction potential, opportunity, susceptibility, and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Inglewood Quadrangle covers an area of about 62 square miles within the Los Angeles Basin. The study area is densely populated and includes all or parts of the cities of Carson, Compton, Gardena, Hawthorne, Inglewood, Lawndale, Los Angeles, Redondo Beach, and Torrance, as well as unincorporated areas of Los Angeles County. Major transportation routes traversing the Inglewood Quadrangle include the Century Freeway (I-105), the San Diego Freeway (I-405), and the Harbor Freeway (I-110).

The Inglewood Quadrangle, located at the northwestern end of the Peninsular Ranges geomorphic province, contains a northwest-trending uplifted area consisting of the Baldwin Hills and the Rosecrans Hills. The hills are geomorphic features associated with uplift along the Newport –Inglewood structural zone. Older Quaternary units are exposed in these strongly dissected hills, and elevations range from approximately 75 feet to over 400 feet. To the east, Holocene alluvium lies upon the regional coastal basin, also known as the Downey Plain. The sediments overlie an erosional surface of late Pleistocene age. To the west of the Rosecrans Hills is an elevated plain underlain by older Quaternary alluvium. This area contains a drainage basin, with Holocene sediments, that narrows to the south into the Dominguez Channel. Within the southwestern corner of the quadrangle Pleistocene dune sand overlies older alluvial deposits.

The main drainage courses within the quadrangle are the Dominguez Channel, Compton Creek, and Centinela Creek.

GEOLOGIC CONDITIONS

Surface Geology

A digital map obtained from the U.S. Geological Survey (Tinsley, unpublished) was used as a base to prepare a geologic map of the Inglewood Quadrangle for this project. Other geologic maps reviewed include Castle (1960), Weber and others (1982), Poland and others (1959), CDWR (1961), and a digital map prepared by the Southern California Areal Mapping Project (SCAMP, unpublished). Geologic contacts were modified using the sources listed above, air photos (Fairchild, 1927), and older topographic maps (USGS, 1930, 1942,1924a, and 1924b). Stratigraphic nomenclature was revised to follow the format developed by SCAMP (Morton and Kennedy, 1989). The revised geologic map that was used in this study of liquefaction susceptibility is included as Plate 1.1.

The oldest geologic units mapped in the Inglewood Quadrangle are the Pleistocene Inglewood Formation (Qi) and San Pedro Formation (Qsp) which are exposed in the Baldwin Hills. A reddish brown, well-cemented and resistant, locally pebbly or gravelly, silty sand caps some of the ridges in this area and is designated older alluvium (Qoa). A more detailed description of the geology of the Baldwin Hills is presented in Section 2.

Quaternary sediments covering the remainder of the Inglewood Quadrangle include older eolian deposits (Qoe), which form a portion of the El Segundo Sand Hills that extends into the southwestern corner of the map, older alluvium (Qoa) deposited around the margin of the Baldwin Hills and on the elevated plain and Rosecrans Hills to the south, younger alluvial-fan deposits (Qyf) just west of the center of the quadrangle, and younger floodplain and stream deposits (Qya2) in the northeastern and south-central portion of the map as well as along the Centinela Creek drainage

Subsurface Geology and Geotechnical Characteristics

Several hundred borehole logs drilled within the Inglewood Quadrangle were collected at the California Department of Transportation (Caltrans); the Department of Water Resources; the Los Angeles County Department of Public Works; the California Regional Water Quality Control Board - Los Angeles Region; DMG Environmental Review and Hospital Review Projects; and the U.S. Geological Survey (USGS). The USGS supplied paper logs of the Los Angeles County of Public Works storm drain borehole data. These logs were used in earlier liquefaction studies of the Los Angeles area (Tinsley and Fumal, 1985; Tinsley and others, 1985).

Lithologic, soil test, and related data from approximately 246 logs were entered into the DMG (Geographic Information System) database. The remaining logs were reviewed during this investigation to aid with the stratigraphic correlation. Locations of all exploratory boreholes entered into the database are shown in Plate 1.2.

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are generalized to give the characteristics of the unit most commonly encountered.

Older alluvium (Qoa) and older eolian deposits (Qoe)

In general, the older alluvium of the Rosecrans Hills, the Baldwin Hills, and the Gardena area consists of stiff to hard clay and medium dense to very dense sand, silty sand, clayey sand and silt.

Within the western and southwestern portion of the Inglewood Quadrangle, the elevated plain consists of older alluvium overlain, in part, by stabilized older dunes. The dune sand is up to 15 feet thick and is composed of medium dense fine silty sand and silt. Locally, the top 10 feet of this unit is very loose. Underlying and adjacent to this unit, the older alluvium is medium dense to very dense sand, silty sand, clayey sand and silt, and very stiff clay. Locally, in the Lawndale area at a depth of 25 to 30 feet, there occurs a 20- to 25-foot thick unit of loose to medium dense silt, fine sand and shell material.

Younger alluvium (Qyf, Qya2)

The younger allluvial fan (Qyf) in the central portion of the quadrangle is composed of medium dense to very dense sand, silty sand, and silt, and stiff clay. This unit appears to be up to 45 feet thick, however the borehole characteristics become indistinguishable from the underlying older alluvium with depth. The younger alluvial valley deposits (Qya2) mapped in this portion of the quadrangle consists of approximately 10 to 20 feet of soft to firm clay and clayey sand. These materials overlie dense sands and stiff clays of older alluvium.

The younger alluvial valley deposits (Qya2) of the northeastern portion of the quadrangle consist predominately of loose to dense sands, silty sands, and silts. Clay units are locally present, but become much more dominant adjacent to the Rosecrans Hills.

GROUND-WATER CONDITIONS

A ground-water evaluation of alluviated areas was performed in order to determine historically shallow ground-water levels in the Inglewood Quadrangle. Areas characterized by historical ground-water or perched water with depths of less than 40 feet are considered for the purposes of liquefaction hazard zoning. The evaluation relied heavily on turn of the century water-well logs (Mendenhall, 1905), and water measurements from borehole logs collected for this study. Other reports that were reviewed include Poland and others (1959), California Department of Water Resources (1961), and California Department of Public Works (1952). The depths to first encountered water free of piezometric influences were plotted and contoured onto a map showing depths to historically shallowest ground water (Plate 1.2). This map was digitized and used for the liquefaction analysis. The map was compared to similar published maps for any discrepancies (Tinsley and others, 1985; Leighton and others, 1990). Plate 1.2 shows that historical shallow water conditions (less than 40 feet depth) occurred within the Inglewood Quadrangle.

In the late 1800's many shallow wells showed near-surface water levels particularly in those areas already known to have deeper artesian conditions (Mendenhall, 1905). Subsequent management and withdrawal of ground water markedly reduced the distribution of both of these conditions. Although the potential for recharge is beyond the scope of this report, the review of 100's of boreholes, and conclusions from California Department of Water Resources (1961) and Tinsley and others (1985), all suggest that water could move upward into semi-perched zones if pressure levels in the underlying units become sufficiently high, due to the discontinuous character and high sand content of the confining units.

PART II

EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of methods for mapping liquefaction hazard have been proposed; Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of susceptibility units, and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to evaluate liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the Inglewood Quadrangle, peak accelerations of 0.44 g to 0.50 g resulting from an earthquake of magnitude 6.7 to 7.1 were used for liquefaction analyses. The PGA and magnitude values were derived from maps prepared by Petersen and others (1996) and Cramer and Petersen (1996), respectively. See the ground motion section of this report for further details.

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. Primarily, physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance. Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense. Cohesive soils are generally not considered susceptible to liquefaction.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil-property and soil-condition factors such as type, age, texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related to the map units. DMG's qualitative susceptible soil inventory is summarized below.

Younger alluvium (Qyf, Qya2)

The younger alluvial valley (Qya2) deposits in the north and eastern portion of the Inglewood Quadrangle consist largely of loose to dense sands and silts. Where historical ground water levels are within 40 feet of the surface, these deposits are judged to be susceptible to liquefaction.

The younger alluvial fan (Qyf) unit in the central portion of the quadrangle is dense to very dense and is considered to have a low potential for liquefaction. Similarly the younger alluvial valley deposits (Qya2) in this vicinity are also considered to have a low potential for liquefaction. The Qya2 units are generally stiff clays that lie above the historically high ground-water elevation.

Older alluvium (Qoa, Qoe)

Most of the old Quaternary sedimentary deposits of the Inglewood Quadrangle are described in borehole logs as being medium dense to very dense sand, silt, and clay. In general, these deposits are considered to have a low liquefaction susceptibility. Within the western and southwestern portion of the Inglewood Quadrangle some loose dune sand does occur, however this unit is located above the historical high ground-water level. Locally, in the Lawndale area at a depth of 25 to 30 feet, there occurs a loose to medium dense unit of sand, silt and shell debris in an area where the historical high ground water is at less than 40 feet. Although the liquefaction analysis performed on these layers results in factors of safety of less than one, the unit is overlain by 15 to 20 feet of very dense to dense sand, and is, therefore, considered to have a low susceptibility.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses, expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. FS, therefore, is a quantitative measure of liquefaction potential. Generally, a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, indicates the presence of potentially liquefiable soil. DMG uses FS, as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil, to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation.

Approximately 92 percent of the borehole logs reviewed in this study (Plate 1.2) contained blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Few borehole logs, however, included all of the information (soil density, moisture content, sieve analysis, etc) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values or average test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.

2. All areas of uncompacted fills containing liquefaction susceptible material that are saturated, nearly saturated, or may be expected to become saturated.

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.

4. Areas where existing geotechnical data are insufficient.

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the Inglewood Quadrangle is summarized below.

Areas of Past Liquefaction

Historic liquefaction has not been confirmed in the Inglewood Quadrangle. However, a depression that developed in the sediments of Centinela Creek Valley as a result of the 1920 Inglewood earthquake about two to three miles northwest of Inglewood City Hall (in the adjacent Venice Quadrangle) is suggestive of liquefaction. In his discussion of the effects of the June 21, 1920, Inglewood earthquake, Taber described and pictured (1920, p. 140 and Plate 14, figure 2) a "low ridge about one and one half feet high and fifteen feet broad" that crossed the furrows in a farm field in the Centinela Creek Valley just west of the boundary of the Inglewood 7.5-minute Quadrangle. He also described a depression that had developed between the ridge and another, parallel one about one hundred yards to the northeast. No evidence of paleo-seismic liquefaction has been reported. Therefore, no areas within the Inglewood Quadrangle are zoned for potential liquefaction hazard based on historic liquefaction.

Artificial Fills

Non-engineered artificial fills have not been delineated or mapped in the Inglewood Quadrangle. Consequently, no areas within the Inglewood Quadrangle are zoned for potential liquefaction hazard based on their presence.

Areas with Existing Geotechnical Data

Borehole logs, which generally included penetration test data and reasonably sufficient lithologic descriptions, were used to determine the areas of high liquefaction susceptibility. Accordingly, these areas are zoned as potential liquefaction hazard areas based on adequate existing geotechnical data.

Areas of Insufficient Geotechnical Data

Younger alluvium deposited in stream channel and active wash areas generally lacks adequate geotechnical borehole information. The soil characteristics and ground-water conditions in these cases are assumed to be similar to deposits where subsurface information is available. The stream channel and active wash deposits, therefore, are included in the liquefaction zone for reasons presented in criteria item 4a above.

ACKNOWLEDGMENTS

The author thanks the staff of the California Department of Transportation (Caltrans) and the Department of Water Resources; the Los Angeles County Department of Public Works; the California Regional Water Quality Control Board - Los Angeles Region; and John Tinsley of the

USGS for their assistance in the collection of subsurface borehole data. Special thanks to Bob Moskovitz, Teri McGuire, Scott Shepherd, Barbara Wanish and Joy Arther for their GIS operations support, and for designing and plotting the graphic displays associated with the liquefaction zone map and this report.

REFERENCES

Barrows, A.G., 1974, A review of the geology and earthquake history of the Newport-Inglewood structural zone, southern California: California Department of Conservation, Division of Mines and Geology, Special Report 114, 115 p.

California Department of Public Works, 1952, Draft of Report of Referee, West Coast Basin Reference, in the Superior Court of the State of California in and for the County of Los Angeles, California Water Service Company, a corporation, *et al*., Plaintiffs, vs. City of Compton, *et al.* and Alexander Abercromby, *et. al*., Defendants, no. 506806, 175 p.

California Department of Water Resources, 1961, Planned utilization of the ground water basins of the Coastal Plain of Los Angeles County, Appendix A, Ground water geology: California Department of Water Resources Bulletin 104, 181 p.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California State Mining and Geology Board, in press, Criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 21 p.

Castle, R.O., 1960, Geologic map of the Baldwin Hills area, California: U.S. Geological Survey Open-File Report, scale 1:12,000.

Conkling, H., 1927, San Gabriel investigation: California Division of Water Resources Bulletin 5, 640 p.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.

Hillis, D., 1933, Cracks produced by Long Beach, California, earthquake: American Association of Petroleum Geologists Bulletin, v. 17, p. 739-740.

Leighton and Associates, Inc., 1990, Hazard reduction in Los Angeles County: Technical Appendix to the Safety Element of the Los Angeles County General Plan, Department of Regional Planning, County of Los Angeles, 2 v.

Mendenhall, W.C., 1905, Development of underground waters in the western coastal plain region of southern California: U.S. Geological Survey Water-Supply Paper 139, 105 p.

Morton, D.M. and Kennedy, M.P., 1989, A southern California digital 1:100,000-scale geologic map series—The Santa Ana Quadrangle—The first release: Geological Society of America Abstracts with Programs v. 21, no. 6, p. A107-A108.

Petersen, M.D., Cramer, C.H., Bryant, W.A., Reichle, M.S. and Toppozada, T.R., 1996, Preliminary seismic hazard assessment for Los Angeles, Ventura, and Orange counties, affected by the 17 January 1994 Northridge earthquake: Bulletin of the Seismological Society of America, v. 86, no. 1B, p. S247-S261.

Poland, J.E., Garrett, A.A. and Sinnott, A., 1959, Geology, hydrology, and chemical character of ground waters in the Torrance-Santa Monica area, California: U.S. Geological Survey Water Supply Paper 1461, 425 p.; Plate 1, north half, scale 1: 31,680.

Saucedo, G., in progress, Digital geologic map of the Inglewood 7.5-minute Quadrangle, California Department of Conservation, Division of Mines and Geology, Open-File Report, scale 1:24,000.

Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.

Seed, H.B. and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of American Society of Civil Engineers, v. 97: SM9, p. 1,249-1,273.

Seed, H.B., Idriss, I.M. and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Stewart, J.P., Bray, J.D., Seed, R.B. and Sitar, N., 1994, Preliminary report on the principal geotechnical aspects of the January 17, 1994 Northridge earthquake: Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley, Report No. UCB/EERC-94/08.

Taber, Stephen, 1920, The Inglewood earthquake in southern California, June 21, 1920: Bulletin of the Seismological Society of America, v. 10, no. 3, p. 129-145.

Tinsley, J.C. and Fumal, T.E., 1985, Mapping Quaternary sedimentary deposits for areal variations in shaking response, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles Region—An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 101-125.

Tinsley, J.C., Youd, T.L., Perkins, D.M. and Chen, A.T.F., 1985, Evaluating Liquefaction potential, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles Region—An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-315.

U.S. Geological Survey, 1930 edition, Topographic map of the Inglewood 6-Minute Quadrangle, scale 1:24,000, contour interval 5 feet.

U.S. Geological Survey, 1942 reprinted edition, Topographic map of the Watts 6-Minute Quadrangle, scale 1:24,000, contour interval 5 feet.

U.S. Geological Survey, 1924a edition, Topographic map of the Torrance 6-Minute Quadrangle, scale 1:24,000, contour interval 5 feet.

U.S. Geological Survey, 1924b edition, Topographic map of the Compton 6-Minute Quadrangle, scale 1:24,000, contour interval 5 feet.

Weber, F.H., Jr., Hsu, E.Y., Saul, R.B., Tan, S.S. and Treiman, J.A., 1982, Slope Stability and Geology of the Baldwin Hills, Los Angeles County, California: California Division of Mines and Geology Special Report 152, 93 p., scale 1:4,800

Wood, H.O., 1933, Preliminary report on the Long Beach earthquake: Bulletin of the Seismological Society of America, v. 23, p. 43-56.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.

Youd, T.L. and Idriss, I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research, Technical Report NCEER-97-0022

Youd, T.L. and Perkins, D.M. 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

AIR PHOTOS

Fairchild Aerial Surveys, Flight 113, 1927, Frames 131-138 and 171-178, black and white, vertical, scale 1:19,000.

U.S. Geological Survey, NAPP Aerial Photography, May 31, 1994, Flight 6858, Frames 28-32 and 45-49, black and white, vertical, scale 1:40,000.

SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Inglewood 7.5-Minute Quadrangle, Los Angeles County, California

By

Michael A. Silva and Pamela J. Irvine

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Inglewood 7.5-minute Quadrangle (scale 1:24,000). This section and Section 1 addressing liquefaction, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Landslides triggered by earthquakes have historically been a major cause of earthquake damage. Landslides triggered by the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes were responsible for destroying or damaging numerous homes and other structures, blocking major transportation corridors, and damaging various types of life-line infrastructure. Typically, areas most susceptible to earthquake-induced landslides are on steep slopes and on or adjacent to existing landslide deposits, especially if the earth materials in these areas are composed of loose colluvial soils, or poorly cemented or highly fractured rock. These geologic and terrain conditions exist in many parts of southern California, most notably in hilly areas already developed or currently undergoing development. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, which includes the Inglewood Quadrangle.

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered primarily from a variety of outside sources; thus the quality of the data is variable. Although the selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Earthquake-generated ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. No attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Inglewood Quadrangle, for more information on the delineation of liquefaction zones.

Information developed in the study is presented in two parts: physiographic, and geologic conditions in PART I, and ground shaking opportunity, landslide hazard potential and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Inglewood Quadrangle covers an area of about 62 square miles within the Los Angeles Basin. The study area is densely populated and includes all or parts of the cities of Carson, Compton, Gardena, Hawthorne, Inglewood, Lawndale, Los Angeles, Redondo Beach, and Torrance, as well as unincorporated areas of Los Angeles County. Major transportation routes traversing the Inglewood Quadrangle include the Century Freeway (I-105), the San Diego Freeway (I-405), and the Harbor Freeway (I-110).

The Inglewood Quadrangle, located at the northwestern end of the Peninsular Ranges geomorphic province, contains a northwest-trending uplifted area consisting of the Baldwin Hills and the Rosecrans Hills. The hills are geomorphic features associated with uplift along the Newport –Inglewood structural zone. Older Quaternary units are exposed in these strongly dissected hills, and elevations range from approximately 75 feet to over 400 feet. To the east, Holocene alluvium lies upon the regional coastal basin, also known as the Downey Plain. The sediments overlie an erosional surface of late Pleistocene age. To the west of the Rosecrans Hills is an elevated plain underlain by older Quaternary alluvium. This area contains a drainage basin, with Holocene sediments, that narrows to the south into the Dominguez Channel. Within the southwestern corner of the quadrangle Pleistocene dune sand overlies older alluvial deposits.

The main drainage courses within the quadrangle are the Dominguez Channel, Compton Creek, and Centinela Creek.

GEOLOGIC CONDITIONS

Surface and Bedrock Geology

A digital map obtained from the U.S. Geological Survey (Tinsley, unpublished) was used as a base to prepare a geologic map of the Inglewood Quadrangle for this project. Other geologic maps reviewed include Castle (1960), Weber and others (1982), Poland and others (1959), CDWR (1961), and a digital map prepared by the Southern California Areal Mapping Project (SCAMP, unpublished). Geologic contacts were modified using the sources listed above, air photos (Fairchild, 1927), and older topographic maps (USGS, 1930, 1942,1924a, and 1924b). In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

Bedrock exposures in the Inglewood Quadrangle are limited to the northwest corner of the map where strata have been uplifted, folded, and faulted along the Newport-Inglewood structural zone to form the Baldwin Hills. The Baldwin Hills are primarily composed of marine sediments of Pleistocene age. Stratigraphic correlation of Plio-Pleistocene and Quaternary strata within the

Los Angeles Basin is difficult because of rapid lateral facies changes resulting from fluctuations in the paleo-shoreline and the time-transgressive nature of the faunal assemblages (Quinn and others, 1997). Because of the current lack of well-defined Quaternary correlations and nomenclature, the formation designations used in this study for the Baldwin Hills area should be regarded as generalized and informal.

The oldest Quaternary unit mapped in the Inglewood Quadrangle is the lower Pleistocene Inglewood Formation (Qi; “A” formation of Castle, 1960), which is exposed along fault traces on the south slope of the Baldwin Hills. It is composed of thinly interbedded siltstone and fine sandstone deposited in a shallow marine environment. Unconformably overlying the Inglewood Formation, is the Pleistocene San Pedro Formation (Qsp; “B” formation of Castle, 1960), which consists of poorly consolidated, fine- to coarse-grained sand interbedded with thin beds and lenses of gravel deposited in a near-shore marine environment (“Qc” in Weber and others, 1982). Also included in this unit are fluvial sand and gravel with local beds of clayey silt (“Qb” in Weber and others, 1982). A reddish brown, well-cemented and resistant, locally pebbly or gravelly, silty sand caps some of the ridges in this area and is designated older alluvium (Qoa; “Qf” in Weber and others, 1982; “cap deposits” in Castle, 1960).

Quaternary sediments covering the remainder of the Inglewood Quadrangle include older eolian deposits (Qoe), which form a portion of the El Segundo Sand Hills that extends into the southwest corner of the map, older alluvium (Qoa) deposited around the margin of the Baldwin Hills and on the elevated plain and Rosecran Hills to the south, younger alluvial-fan deposits (Qyf) just west of the center of the quadrangle, and younger floodplain and stream deposits (Qya2) in the northeastern and south-central portion of the map as well as along the Centinela Creek drainage. Small, surficial landslides (Qls and Qls?) have occurred on the steeper slopes and along roadcuts in the Baldwin Hills. A more detailed discussion of the Quaternary deposits in the Inglewood Quadrangle can be found in Section 1.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they must first be ranked on the basis of their overall shear strength. The primary source for rock shear-strength measurements is geotechnical reports prepared by consultants, on file with local government permitting departments. Shear strength data for the rock units identified on the geologic map were obtained from the City of Los Angeles, Department of Building and Safety and other sources (see Appendix A). The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

Shear strength data gathered from the above sources were compiled for each mapped geologic unit, and subdivided for fine-grained and coarse-grained lithologies if appropriate. Geologic units were grouped on the basis of average angle of internal friction (average f) and lithologic character. When available, shear tests from adjacent quadrangles were used to augment data for geologic formations that had little or no shear test information. For the Inglewood Quadrangle, shear test values used to calculate rock strength were borrowed from adjacent quadrangles. All shear tests for Qi and additional values for Qsp were obtained from the Hollywood Quadrangle.

Additional values for Qoa and Qsp were obtained from the Venice Quadrangle. No shear tests were available for Qyf and this geologic unit was added to existing groups on the basis of lithologic and stratigraphic similarities.

The results of the grouping of geologic materials in the Inglewood Quadrangle are in Tables 2.1 and 2.2.

INGLEWOOD QUADRANGLE SHEAR STRENGTH GROUPINGS							
	Formation Name	**Number Tests**	**Mean/ Median Phi**	**Mean/ Median (Group phi) (deg)**	**Group Mean/Median C (psf)**	**No Data: Similar Geologic Strength**	**Phi Values Used in Stability Analysis**
GROUP 1	Qoe Qi Qoa Qsp	54 33 41 30	31.1/31 29.9/29 29.8/31 28.2/30	30/31	279/222		30
GROUP 2	Qya2	3	26.3/26	26.3/26	300/300	Qyf	26
GROUP 3	Qls	-	-	-	-	-	15

Table 2.1. Summary of the shear strength statistics for the Inglewood Quadrangle.

SHEAR STRENGTH GROUPS FOR THE INGLEWOOD QUADRANGLE		
GROUP 1	**GROUP 2**	**GROUP 3**
Qi Qoa Qoe Qsp	Qya2 Qyf	Qls

Table 2.2. Summary of the shear strength groups for the Inglewood Quadrangle.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. An inventory of existing landslides in the Inglewood Quadrangle was prepared (Irvine, unpublished) by using previous work done in the area (Weber and others, 1979; Weber and others, 1982) and by combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps. Aerial photos used for landslide interpretation include those from Fairchild (1927) and USGS (1994) (see Air Photos). The completed hand-drawn landslide map was scanned, digitized, and the database was attributed with information on confidence of interpretation (definite, probable, or questionable) and other properties, such as activity, thickness, and associated geologic unit(s). A version of this landslide inventory is included with Plate 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY

Design Strong-Motion Record

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. For the Inglewood Quadrangle, the selection was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8 to 7.0
Modal Distance:	2.5 km
PGA:	0.43 to 0.49 g

The strong-motion record selected was the Channel 3 (north horizontal component) University of Southern California Station #14 recording from the magnitude 6.7 Northridge earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a PGA of 0.69 g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

To develop a relationship between the yield acceleration (a_y; defined as the horizontal ground acceleration required to cause the factor of safety to equal 1.0) and Newmark displacements, the design strong-motion record was integrated twice for a given a_y to find the corresponding displacement, and the process repeated for a range of a_y (Jibson, 1993). The resulting curve in

Figure 2.1 represents the full spectrum of displacements that can be expected for any combination of geologic material strength and slope angle, as represented by the yield acceleration. We used displacements of 30, 15 and 5 cm as criteria for rating levels of earthquake shaking damage on the basis of the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.129 and 0.232 g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant to the Inglewood Quadrangle.

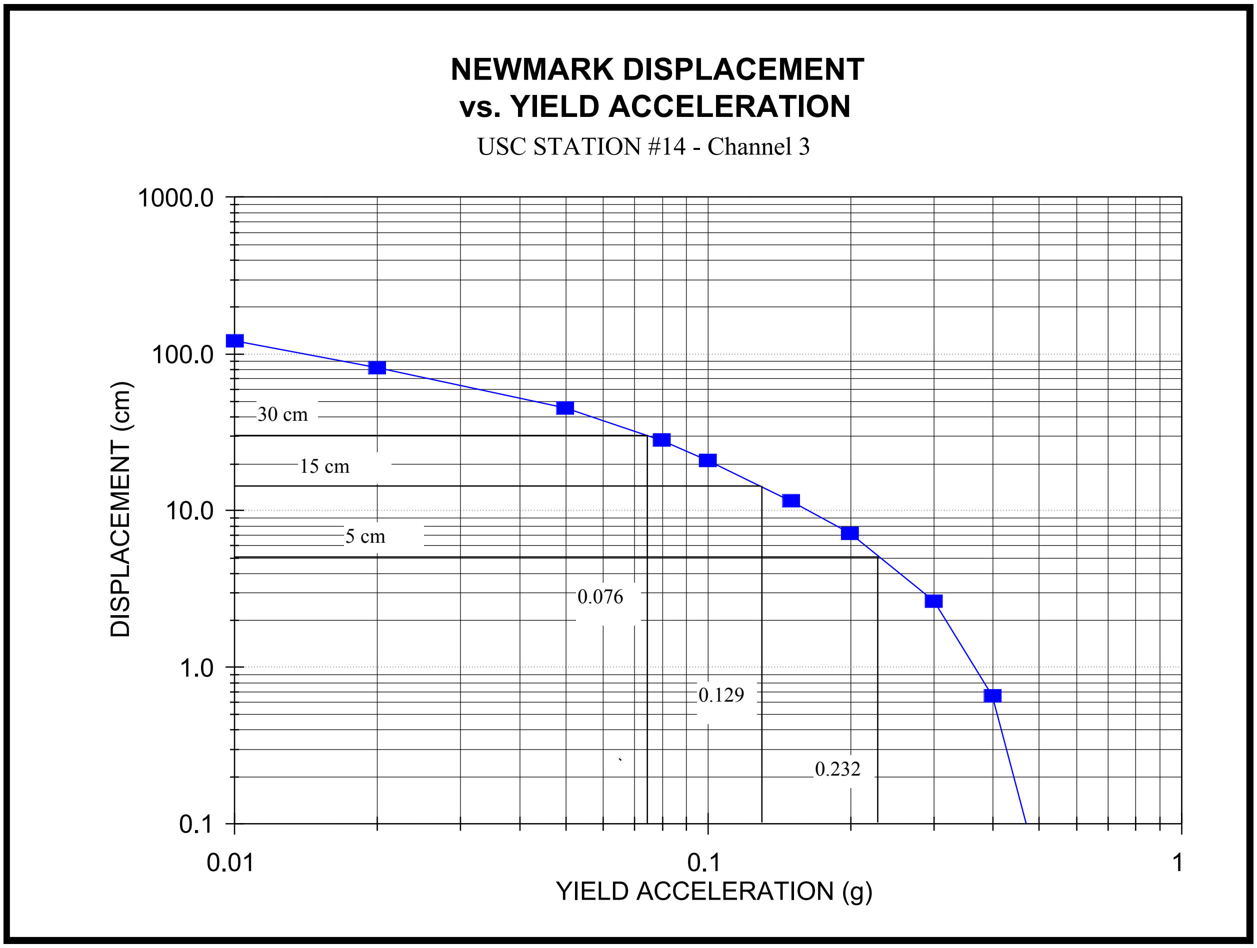


Figure 2.1. Yield acceleration vs. Newmark displacement for the USC Station #14 strong-motion record from the 17 January 1994 Northridge, California Earthquake.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the Inglewood Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle contours, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy. A program that adds a pixel to the edges of the DEM was run twice to avoid the loss of data at the quadrangle edges when the slope calculations were performed. A peak and pit smoothing process was then performed to remove errors in the elevation points.

A slope-gradient map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The slope-gradient map was used with the geologic strength map in preparation of the earthquake-induced landslide hazard potential map.

Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield acceleration calculated by Newmark's equations represents the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. The acceleration values were compared with the ground shaking opportunity, defined by Figure 2.1, to determine the earthquake-induced landslide hazard potential. Based on the criteria described in Figure 2.1 above, if the calculated yield acceleration was less than 0.076g, expected displacements could be greater than 30cm, and a HIGH (H on Table 2.3) hazard potential was assigned. Likewise, if the calculated a_y fell between 0.076 and 0.129g a MODERATE (M on Table 2.3) hazard potential was assigned, between 0.129 and 0.232 a LOW (L on Table 2.3) potential was assigned, and if a_y were greater than 0.232g a VERY LOW (VL on Table 2.3) potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

INGLEWOOD QUADRANGLE HAZARD POTENTIAL MATRIX										
		SLOPE CATEGORY (Percent Slope)								
Geologic Material Group	**Mean Phi**	**I 0-14**	**II 14-19**	**III 19-27**	**IV 27-34**	**V 36-36**	**VI 36-42**	**VII 42-45**	**VIII 45-50**	**IX >50**
1	30	VL	VL	VL	VL	L	L	L	H	H
2	26	VL	VL	VL	L	L	M	H	H	H
3	15	L	M	H	H	H	H	H	H	H

Table 2.3. Hazard potential matrix for earthquake-induced landslides in the Inglewood Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone.

EARTHQUAKE-INDUCED LANDSLIDE ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (in press). Under those criteria, earthquake-induced landslide zones are areas meeting one or more of the following:

1. Areas known to have experienced earthquake-induced slope failure during historic earthquakes.

2. Areas identified as having past landslide movement, including both landslide deposits and source areas.

3. Areas where CDMG's analyses of geologic and geotechnical data indicate that the geologic materials are susceptible to earthquake-induced slope failure.

Existing Landslides

Studies of the types of landslides caused by earthquakes (Keefer, 1984) show that re-activation of the whole mass of deep-seated landslide deposits is rare. However, it has been observed that the steep scarps and toe areas of existing landslides, which formed as a result of previous landslide movement, are particularly susceptible to earthquake-induced slope failure. In addition, because they have been disrupted during landslide movement, landslide deposits are inferred to be weaker than coherent, undisturbed, adjacent source rocks. Finally, we felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, all existing landslides identified in the inventory with a definite or probable confidence of interpretation were included in the hazard zone.

Geologic and Geotechnical Analysis

On the basis of a DMG pilot study (McCrink and Real, 1996) the earthquake-induced landslide zone includes all areas determined to lie within the High, Moderate and Low levels of hazard potential. Therefore, as shown in Table 2.3, geologic strength group 3 is always included in the zone (mapped landslides): strength group 2 materials are included in the zone for all slope gradients above 27%; and strength group 1 materials, the strongest rock types, are zoned for slope gradients above 34%. This results in less than 0.1% of the land in the quadrangle lying within the hazard zone.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Geologic material strength data were collected at the City of Los Angeles with the assistance of Nicki Girmay. Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Scott Shepherd and Barbara Wanish for their GIS operations support, and to Barbara Wanish for designing and plotting the graphic displays associated with the hazard zone map and this report.

REFERENCES

Brabb, E.E., 1983, Map showing direction and amount of bedding dip of sedimentary rocks in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1257C, 1 sheet, scale 1:62,500.

California Department of Water Resources, 1961, Planned utilization of the ground water basins of the coastal plain of Los Angeles County, Appendix A, Ground water geology: California Department of Water Resources, Bulletin No. 104, 181 p.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California State Mining and Geology Board, in press, Criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 21 p.

Castle, R.O., 1960, Geologic map of the Baldwin Hills area, California: U.S. Geological Survey Open-File Report, scale 1:12,000.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, p. 1645-1649.

GeoSAR Consortium, 1995, Year 1: Research and development status report for GeoSAR, a radar-based terrain mapping project: U.S. Government's Advanced Research Projects Agency Contract Order No. B335/00, 135 p.

GeoSAR Consortium, 1996, Year 1: Research and development status report for GeoSAR, a radar-based terrain mapping project: U.S. Government's Advanced Research Projects Agency Contract Order No. B378/00, 70 p.

Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the Institute for Electrical and Electronics Eengineering, v. 69, no. 1, p. 14-47.

Irvine, P.J., unpublished, Landslide inventory of the Inglewood 7.5' Quadrangle, Los Angeles County, California: California Division of Mines and Geology, scale 1:24,000.

Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Transportation Research Board, National Research Council, Transportation Research Record 1411, 17 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.

McCrink, T.P. and Real, C.R., 1996, Evaluation of the Newmark method for mapping earthquake-induced landslide hazards in the Laurel 7-1/2 Minute Quadrangle, Santa Cruz County, California: California Department of Conservation, Division of Mines and Geology Final Technical Report for U.S. Geological Survey Contract 143-93-G-2334, 31 p.

Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Geotechnique, v. 15, no. 2, p. 139-160.

Petersen, M.D., Cramer, C.H., Bryant, W.A., Reichle, M.S. and Toppozada, T.R., 1996, Preliminary seismic hazard assessment for Los Angeles, Ventura, and Orange counties, California, affected by the January 17, 1994 Northridge earthquake: Bulletin of the Seismological Society of America, v. 86, no. 1B, p. S247-S261.

Poland, J.E., Garrett, A.A. and Sinotte, A., 1959, Geology, hydrology, and chemical character of ground waters in the Torrance-Santa Monica area, California: U.S. Geological Survey Water Supply Paper 1461, 425 p.; Plate 1, north half, scale 1:31,680.

Quinn, J.P., Ponti, D.J., Hillhouse, J.W. and Powell, C.L. II, 1997, Quaternary chronostratigraphic constraints on deformation and blind thrust faulting, northern Los Angeles basin: Final Technical Report 1434-95-G-2523 to the U.S. Geological Survey.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Southern California Areal Mapping Project, unpublished, Digital geologic map of the Inglewood 7.5-Minute Quadrangle, scale 1:24,000.

Tinsley, J.C., unpublished, Digital Quaternary geologic map of the Inglewood 7.5-Minute Quadrangle, California: U. S. Geological Survey: compilation scale 1:24,000.

Trifunac, M.D., Todorovska, M.I., and Ivanovic, S.S., 1994, A note on distribution of uncorrected peak ground accelerations during the Northridge, California earthquake of 17 January 1994: Soil Dynamic and Earthquake Engineering, v. 13, no. 3, p. 187-196.

U.S. Geological Survey, 1993, Digital Elevation Models: National Mapping Program, Technical Instructions, Data Users Guide 5, 48 p.

U.S. Geological Survey, 1930 edition, Topographic map of the Inglewood 6-Minute Quadrangle, scale 1:24,000, contour interval 5 feet.

U.S. Geological Survey, 1942 reprinted edition, Topographic map of the Watts 6-Minute Quadrangle, scale 1:24,000, contour interval 5 feet.

U.S. Geological Survey, 1924a edition, Topographic map of the Torrance 6-Minute Quadrangle, scale 1:24,000, contour interval 5 feet.

U.S. Geological Survey, 1924b edition, Topographic map of the Compton 6-Minute Quadrangle, scale 1:24,000, contour interval 5 feet.

Weber, F.H., Jr., Hsu, E.Y., Saul, R.B., Tan, S.S. and Treiman, J.A., 1982, Slope Stability and Geology of the Baldwin Hills, Los Angeles County, California: California Division of Mines and Geology Special Report 152, 93 p., scale 1:4,800.

Weber, F.H., Jr., Treiman, J.A., Tan, S.S. and Miller, R.V., 1979, Landslides in the Los Angeles region, California: effects of the February-March rains: California Division of Mines and Geology Open-File Report 79-4, 277 p., scale 1:250,000.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tennessee, 1980, v. 2, p. 7-6-2 to 7-6-26.

AIR PHOTOS

Fairchild Aerial Surveys, Flight 113, 1927, Frames 131-138 and 171-178, black and white, vertical, scale 1:19,000.

U.S. Geological Survey NAPP Aerial Photography, May 31, 1994, Flight 6858, Frames 28-32 and 45-49, black and white, vertical, scale 1:40,000.

APPENDIX A

SOURCES OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Los Angeles, Department of Building and Safety	**140**
CDMG Special Report 152 (Weber and others, 1982)	**19**
CDMG Hospital Site Reviews	**3**
Total number of tests used to characterize the units in the Inglewood Quadrangle	**162**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Inglewood 7.5-Minute Quadrangle, Los Angeles County, California

By

Mark D. Petersen, Chris H. Cramer, Geoffrey A. Faneros, Charles R. Real and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included, are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5- minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple

Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California State Mining and Geology Board, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2, addressing liquefaction and earthquake-induced landslide hazards, constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the seismogenic sources as published in the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

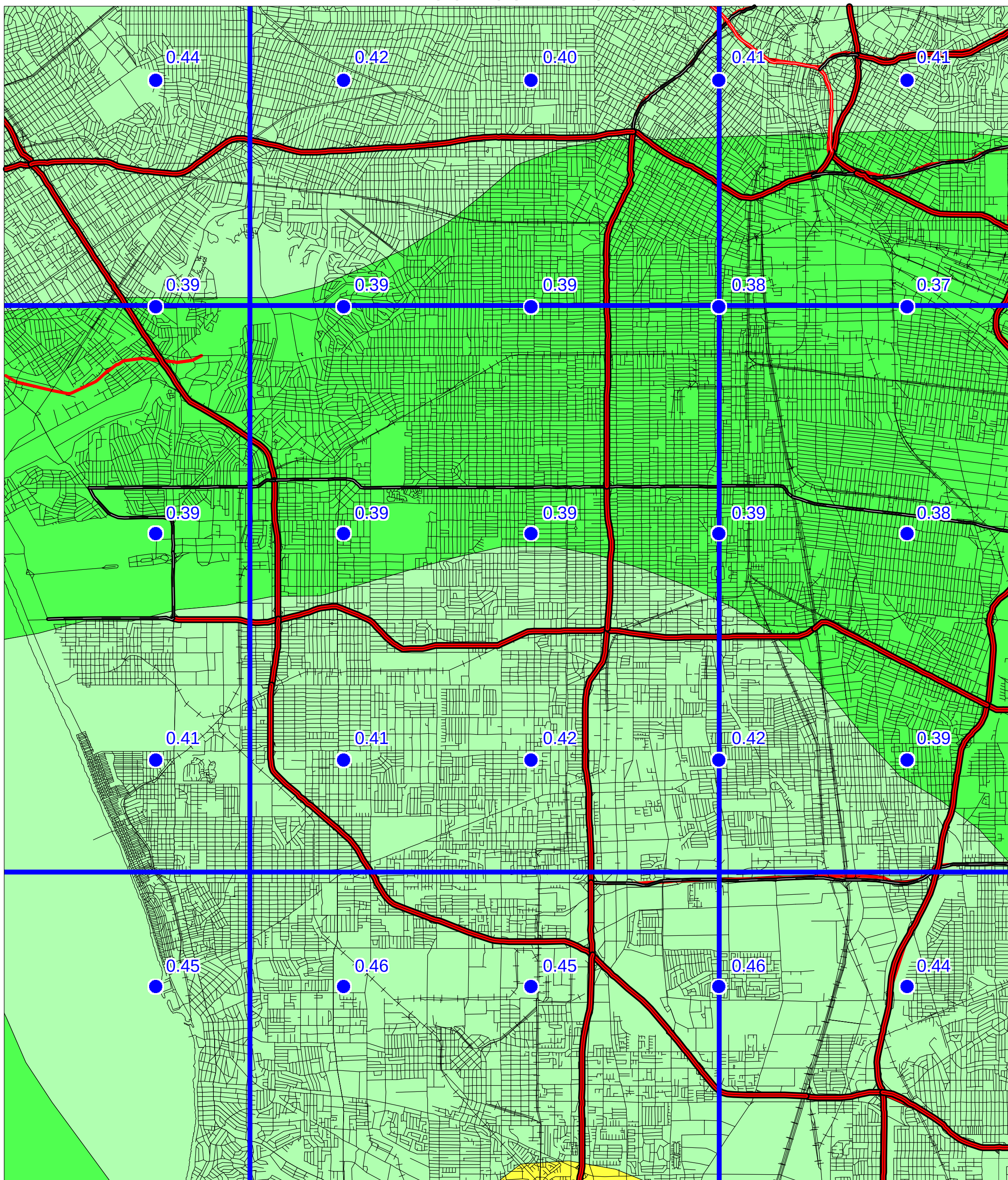
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion

INGLEWOOD 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

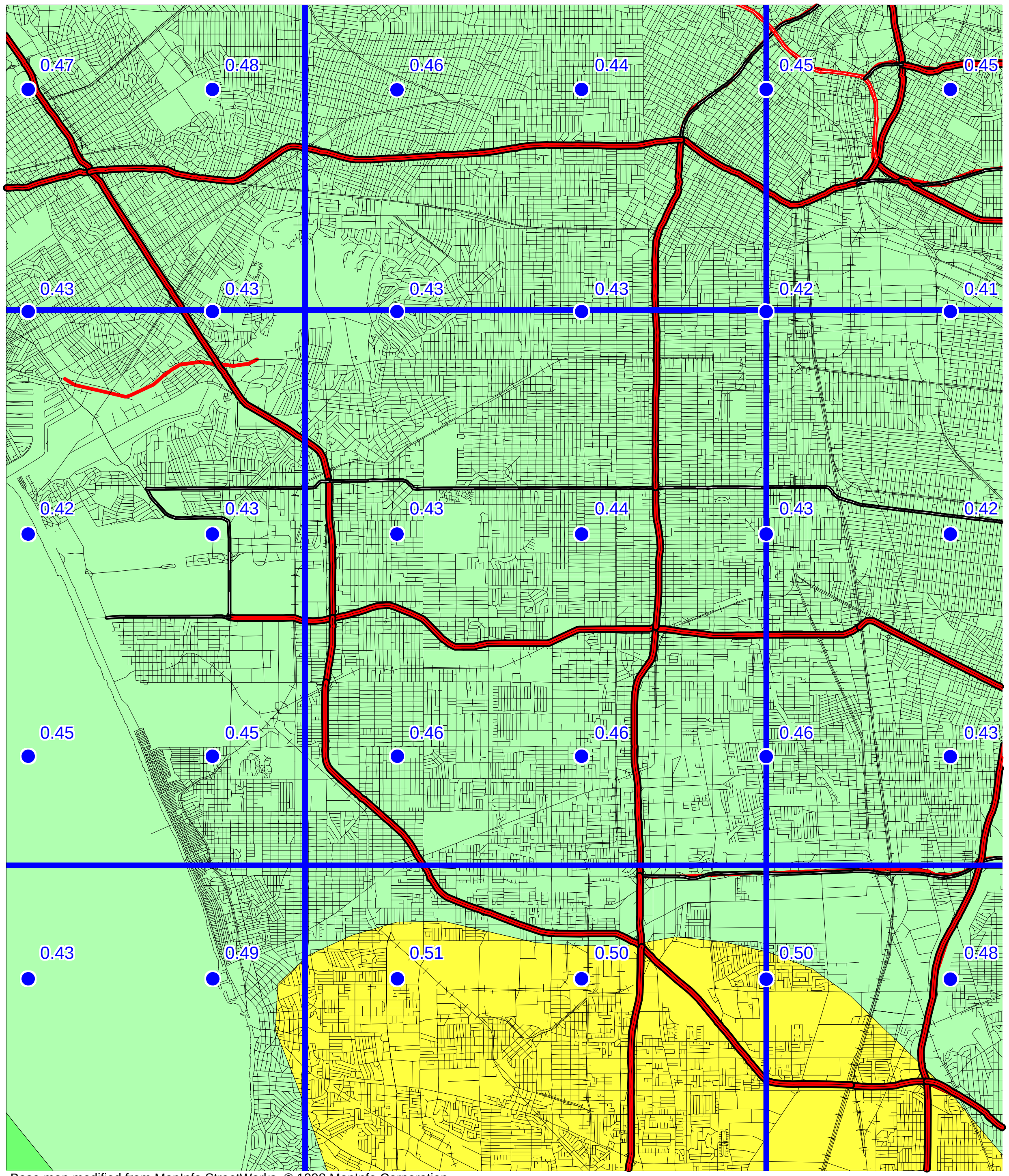
Figure 3.1

INGLEWOOD 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

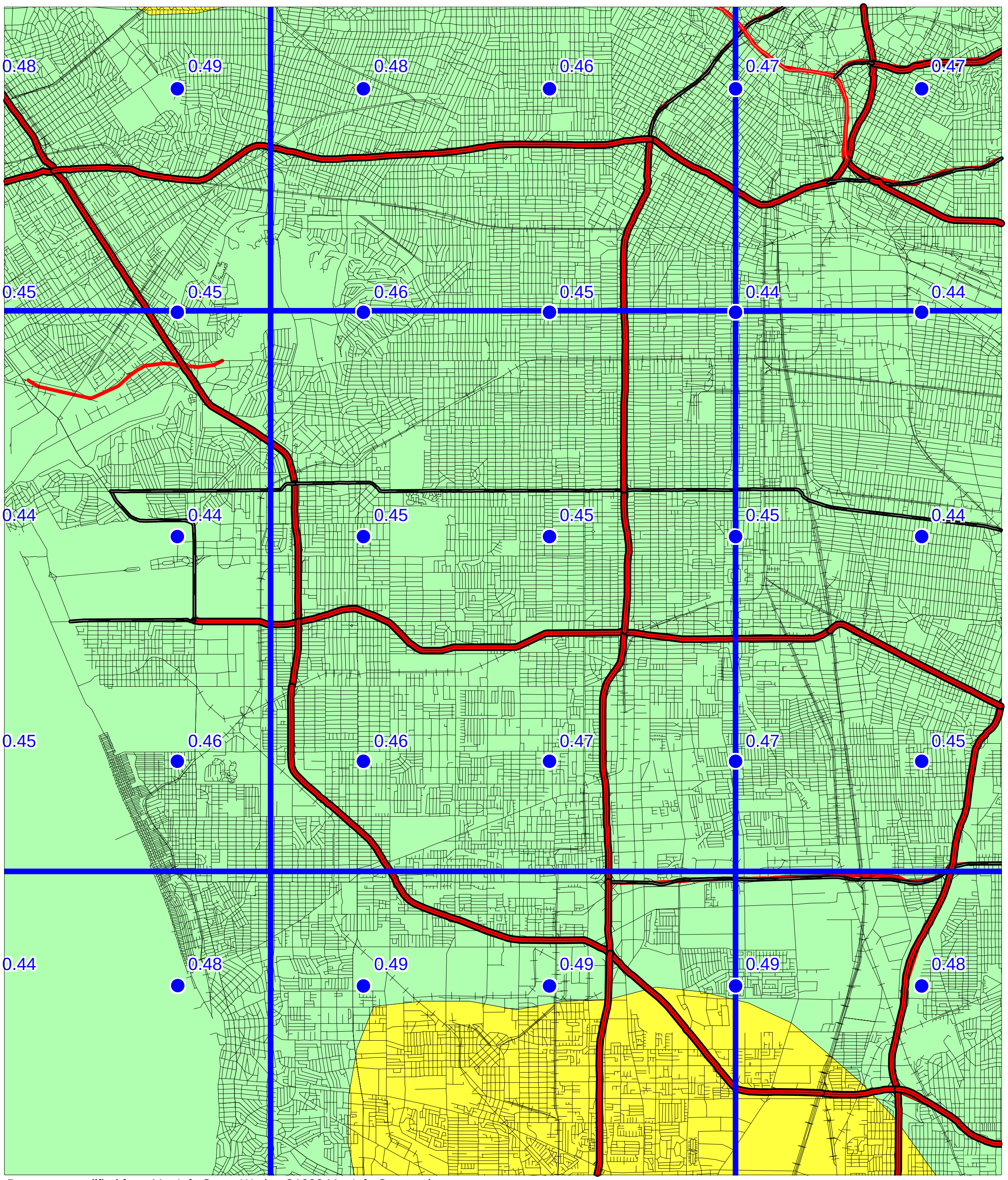
Figure 3.2

INGLEWOOD 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works ©1998 MapInfo Corporation

0 2.5 5

Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.3

values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We

INGLEWOOD 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

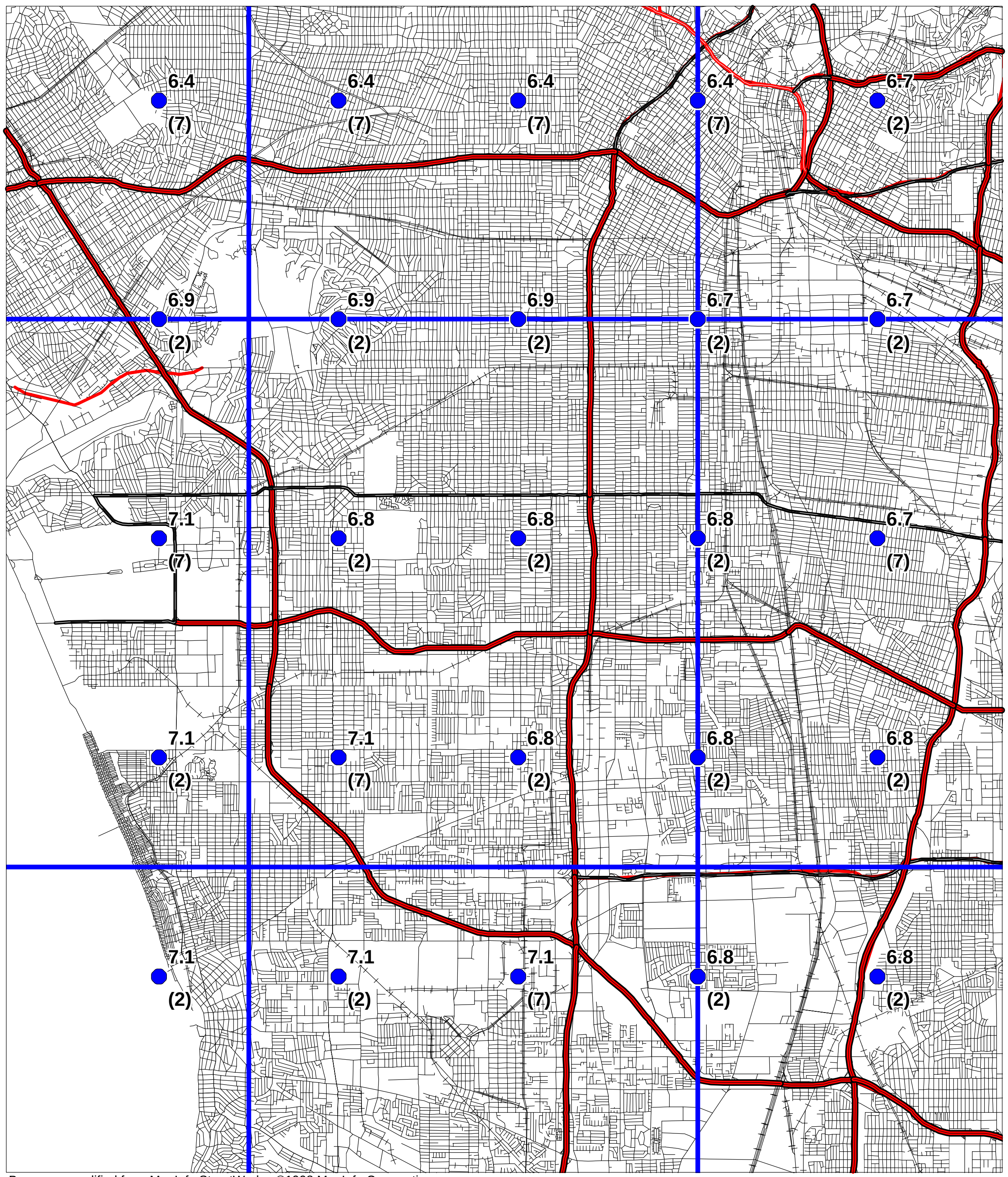
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.4

have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (California State Mining and Geology Board, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the "importance" or sensitivity of the proposed building with regard to occupant safety.

REFERENCES

Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, v. 68, p. 154-179.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, p. 180-189.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, p. 1645-1649.

Cramer, C.H., Petersen, M.D. and Reichle, M.S. 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: Bulletin of the Seismological Society of America, v. 86, p. 1681-1691.

International Conference of Building Officials, 1997, Uniform Building Code: v. 2, Structural engineering and installation standards, 492 p.

Jennings, C.W., *compiler*, 1994, Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, Map No. 8.

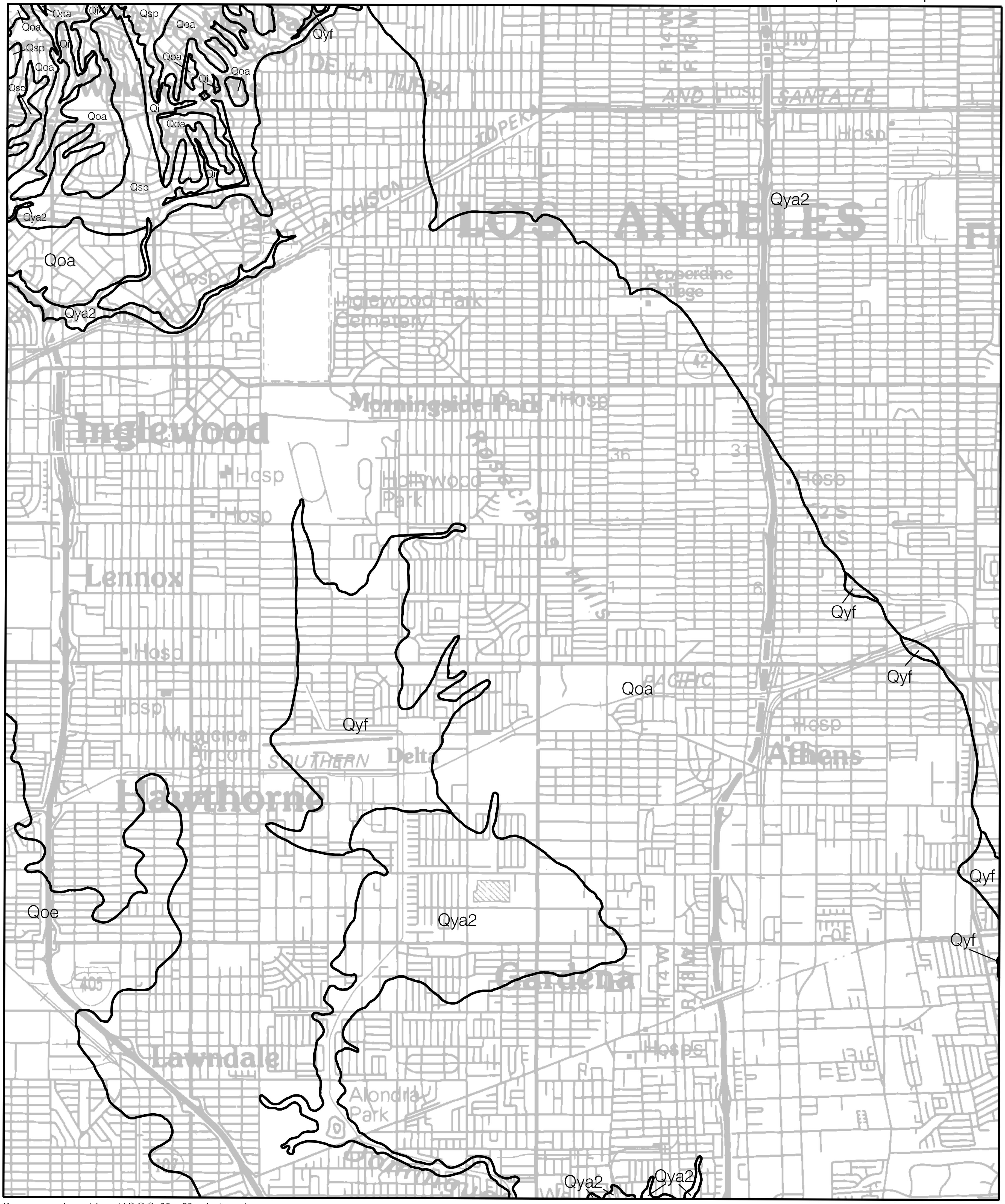
Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 66 p.

Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96—A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L. and Idriss, I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research, Technical Report NCEER-97-0022, 40 p.

Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.



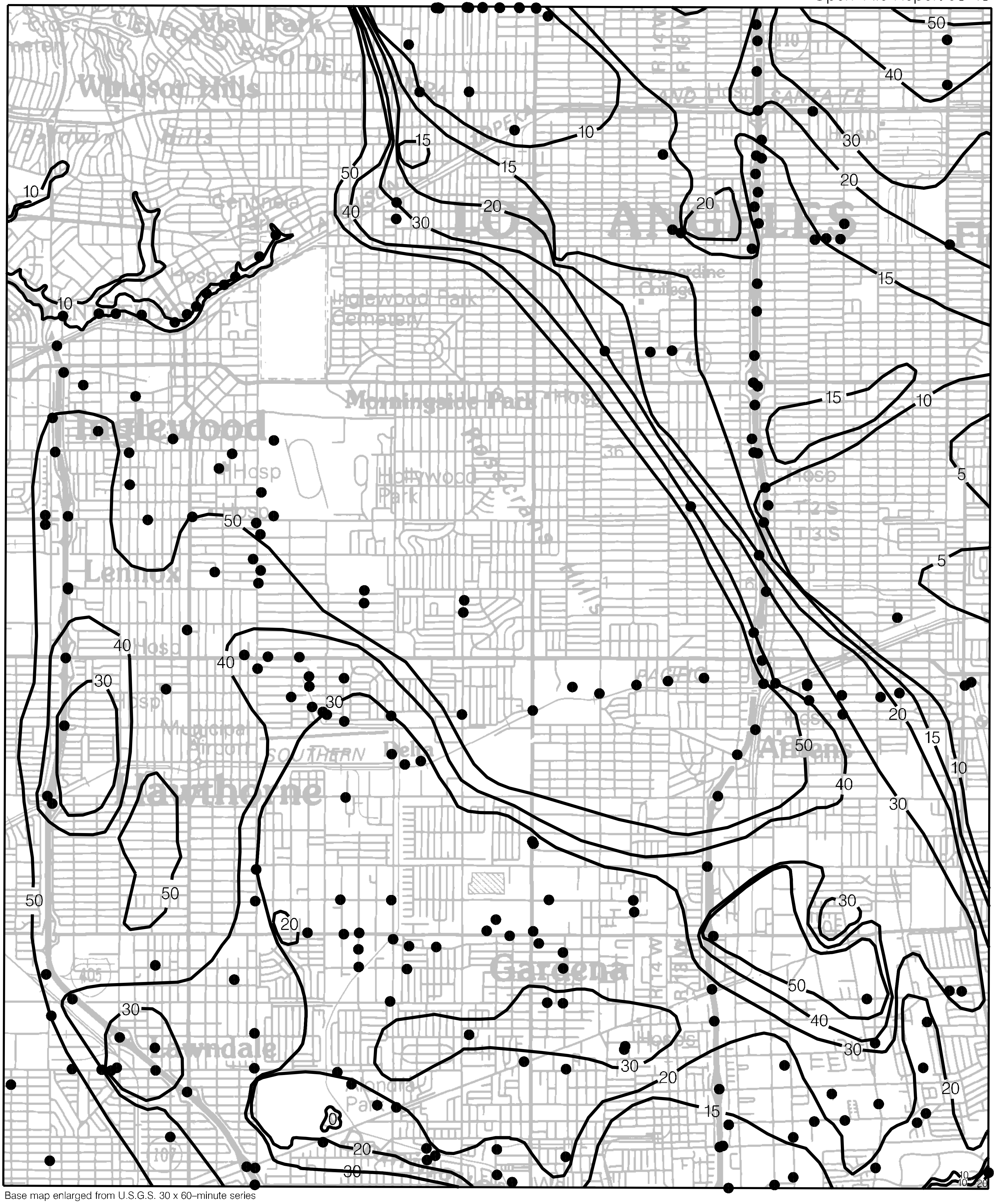
Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 1.1 Quaternary Geologic Map of the Inglewood Quadrangle.

See Geologic Conditions section in report for descriptions of the units.

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

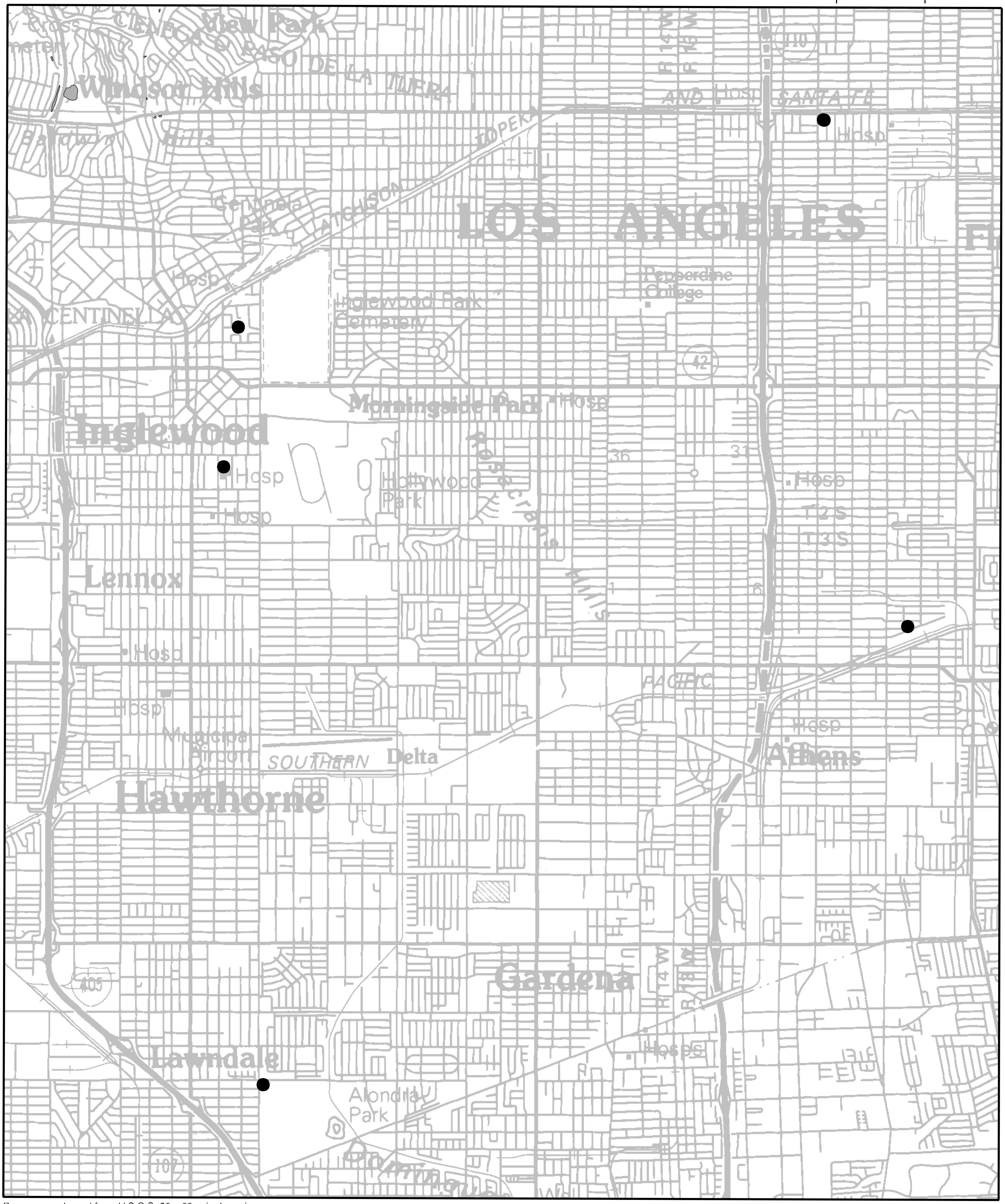
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Inglewood Quadrangle.

● Borehole Site

30 Depth to ground water in feet

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 2.1 Landslide inventory, Shear Test Sample Locations, Inglewood Quadrangle.

● shear test sample location   landslide

ONE MILE

SCALE